*Desalination and Water Treatment*
www.deswater.com

doi: 10.5004/dwt.2023.29503

292 (2023) 176–184
April

# Gemini cationic surfactant based 4-(dimethylamino)benzaldehyde: surface characteristics and biological activity, a straightforward one-step synthesis

Mahmoud Bekhit[a,*], Samir H. Shafek[a], Mohammed M. Younus[b]

[a]*Petrochemicals Department, Egyptian Petroleum Research Institute, Nasr city, Cairo 11727, Egypt, Tel./Fax: +201229575582; email: m.bekhit85@gmail.com (M. Bekhit)*
[b]*Special Processes Lab, Processes Design and Development Division Egyptian Petroleum Research Institute, Nasr City, Cairo 11727, Egypt*

Received 9 December 2022; Accepted 26 March 2023

**ABSTRACT**

A novel three Gemini cationic surfactants was created in this study by one step of alkylating 4-(dimethylamino)benzaldehyde with 1,6-dibromohexane, 1,8-dibromooctane, and 1,10-dibromodecane in acetone. The chemical structures of the generated cationic surfactants were examined using Fourier-transform infrared spectroscopy and proton nuclear magnetic resonance ($^1$H NMR). After measuring the surface tension at various temperatures, the surface parameters, including the critical micelle concentration (CMC), effectiveness ($\pi_{CMC}$), maximum surface excess ($\Gamma_{max}$), efficiency ($Pc_{20}$), and minimum surface area ($A_{min}$), were calculated. Adsorption and micellization's thermodynamic characteristics were calculated, and the results revealed that both processes are spontaneous. It is clear that the Gemini surfactants created have a high tendency to adsorb at the interfaces as well as micellize in the majority of their solutions. The antibacterial activity of the generated surfactants against Gram-negative, Gram-positive, and fungus was examined. The Gemini surfactants' antibacterial effectiveness was enhanced from 22 to 36 mm by an increase in their hydrophobicity and spacer length.

*Keywords:* Gemini surfactants; Surface properties; Antimicrobial activities

## 1. Introduction

Gemini amphiphiles consist of two identical amphiphilic (surface active) moieties connected by a spacer group at or very near the level of the head groups [1,2], or dimeric surfactant [3]. It may be receiving greater attention in academic and industry research laboratories since it seems to be superior to the similar traditional monomeric surfactants (which consist of a head group and a hydrophobic moiety). They have a much lower critical micelle concentration (CMC), lower water surface tension and improve the wetting and dispersing properties of lime soap. Moreover, at low concentrations, a number of Gemini surfactants display intriguing rheological characteristics. Dual wetting agent research is based on the assumption that combining wetting agents in a two-by-two (or three-by-three) arrangement can open new possibilities for wetting agent formation [3–7]. Note that Gemini surfactants with polymethylene hydrophobic spacers are a far cry from the head group bola surfactants with branched alkyl chains and have no special properties. Additionally, Gemini compounds exhibit excellent antibacterial, antiviral, antifungal, and anti-yeast activity [8]. In some circumstances, the Gemini surfactants' minimum inhibitory concentration (MIC) was even three orders of magnitude lower than the concentration of a single surfactant [9,10]. According to some researchers, against dangerous bacteria and fungi, many cationic surfactants have modest antibacterial action. [4,11–14]. Comparison

* Corresponding author.

with Gemini cationic surfactants. The main advantage of new generation surfactants over conventional surfactants is their rapid and complete biodegradation after use. It can be challenging to salvage or recycle surfactants dissolved in water. Hydrolysis of carbonate like cations by environmental microbial enzymes may be the first step in their biodegradation older surfactants will be considered biodegradable if the quaternized degradation product (HX) exhibits better biodegradability. This study describes the prepared Gemini cationic surfactants (Fig. 1) with various spacer chain lengths, and the influence of the spacer lengths on surface properties, including foaming, surface tension, emulsification and thermodynamic adsorption/micellization parameters. Using the well diffusion method, the effectiveness of the Gemini cationic surfactants produced as antimicrobial agents was evaluated utilizing the depletion method, the biodegradability of surfactants produced in river water was assessed.

## 2. Materials and methods

### 2.1. Materials

4-(dimethylamino)benzaldehyde (99%) was purchased from Merck (Germany). 1,10-dibromodecane, 1,8-dibromooctane and 1,6-dibromohexane (98%) supplied by Aldrich Chemical Company (Germany). All reagents and solvents received from Biochem (Egypt). Were used without further purification.

### 2.2. Instrumentation

The compound structure of the synthetic surfactant (Fig. 1) was established by the following methods: Infrared spectroscopy: of the synthetic surfactant was done using a Fourier-transform infrared (FTIR) spectrophotometer, using potassium bromide disc method; proton nuclear magnetic resonance ($^1$H NMR) spectra: $^1$H NMR spectra were verified using a Varian Mercury-300 MHz spectrometer with trimethylsilane (TMS) as inner ordinary and DMSO-D6 as solvent.

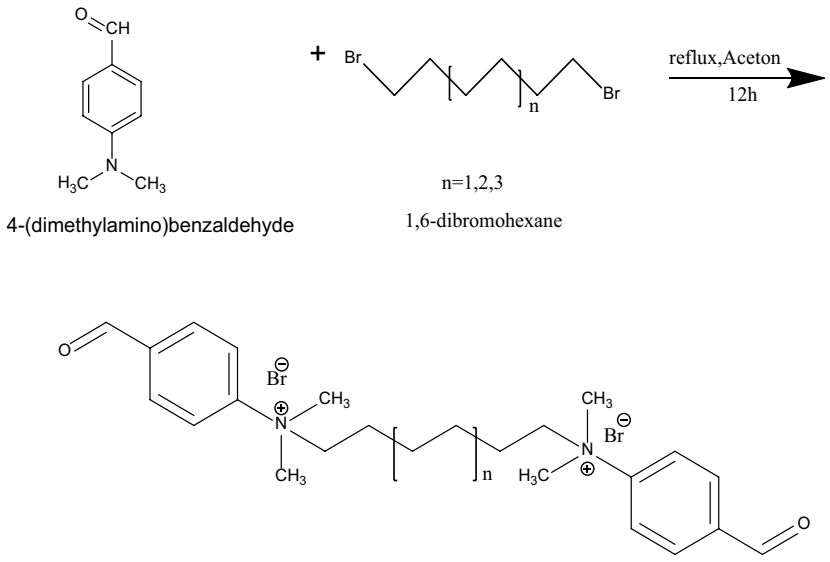
### 2.3. Synthesis

Dibromo alkanes, especially 1,6-dibromohexane, 1,8-dibromooctane and 1,10-dibromodecane (0.1 mol) with 4-(dimethylamino)benzaldehyde (0.2 mol) coupling reaction in 50 mL of acetone, resulting in a double surfactant. Refluxed for 12 h, the cationic compound was completely precipitated from the reaction mixture. To prepare the necessary Gemini cationic surfactants (G6, G8 and G10), the resulting di-quaternary ammonium salts were filtered and recrystallized three times from acetone [15]. The process of synthesis of Gemini cationic surfactants is shown in Scheme1.

### 2.4. Measurements

#### 2.4.1. Surface tension

The platinum ring method was used to measure surface tension with a Krüss K6 tensiometer (Germany). In order for the produced Gemini cationic surfactants to stabilize and fully adsorb at the solution surface, the solutions were poured into a clean Teflon cup and allowed to sit for 2 h before being measured for surface tension at 25°C. The surface tension readings, which were measured at least three times, were taken as the average for the recorded results. The surface tension profile was used to calculate the CMC and surface parameters [16].




n=1: $N^1$,$N^6$-bis(4-formylphenyl)-$N^1$,$N^1$,$N^6$,$N^6$-tetramethylhexane-1,6-diaminium bromide
n=2: $N^1$,$N^6$-bis(4-formylphenyl)-$N^1$,$N^1$,$N^6$,$N^6$-tetramethyloctane-1,6-diaminium bromide
n=3: $N^1$,$N^6$-bis(4-formylphenyl)-$N^1$,$N^1$,$N^6$,$N^6$-tetramethyldecane-1,6-diaminium bromide

Fig. 1. The compounds structure of the synthetic surfactants.

*2.4.2. Antimicrobial efficiency*

Produced Gemini surfactants (G6, G8, and G10) were evaluated for their antibacterial activity against a variety of pathogenic bacteria and fungi using erythromycin/metronidazole as the standard. The numerous species of organisms tested were provided by the unit of operation development center in Cairo, Egypt, of the Egyptian Petroleum Research Institute. Nevertheless, species of sulfate-reducing bacteria were obtained from the Cairo, Egypt, microanalysis facility of Cairo University. The following media are used to test the antimicrobial activity of synthetic compounds. The bacterial species grow on nutrient agar, while fungi and mold grow on Czapek's dox agar. Beef extract (3 g/L), sodium chloride (3 g/L), peptone (5.0 g/L), and agar are the components of nutrient agar. An autoclave is used to sterilize the media after the volume reaches 1 L. The liquid is heated to a boil at this point. Czapek's Dox agar contains sucrose (20.0 g/L), magnesium sulfate (0.5 g/L), sodium nitrate (2.0 g/L), ferrous sulfate (0.01 g/L), potassium chloride (0.5 g/L), and agar (20.0 g/L). However, the volume needs to be increased to 1 L, the mixture needs to be heated to boiling, and the media needs to sterilize [17]. The growth of microscopic organisms. In an assay, the following method is used to determine whether an antibiotic can kill or stop the growth of living microorganisms: Diffusion of discagar through filter paper (Kirby–Bauer). The bacterial and fungal strains were grown in a laboratory, as stated by the National Committee for Clinical Laboratory Standards [18]. The widths of restraint zones were determined after 24–48 h at 35°C–37°C (for bacteria) and 3–4 d at 25°C–27°C (for yeast and fungus) of incubation at 28°C, followed by filtration to remove mycelia fragments before the spore-containing solution was used for vaccine. Evaluations of resistance and susceptibility to make discs for inoculation, 50 mL of agar media at 40°C and 1.0 mL of inocula were combined. The room temperature was allowed to set before the agar was poured into the 120 mm Petri plates. Wells with a diameter of 6 mm were drilled into the agar plates with the appropriate sterile tubes. After that, add 0.1 mL of the chemical solution that was made, which is 1 mg of surfactant to 1 mL of dimethyl sulfoxide (DMSO), to the agar. The biocidal action of the synthesised compounds was evaluated by the repression zone these mixtures created contrary to the specific test bacteria in order to measure the breadth of the constraint zones. The plates were placed on a level surface and allowed to hatch for bacteria for 24 h at 30°C. Each sample's zone of development restraint was calculated using the average of three repetitions [19]. The microorganisms used were fungi (*Candida albicans* and *Aspergillus niger*), Gram-positive bacteria (*Bacillus subtilis* and *Staphylococcus aureus*), and Gram-negative bacteria (*Pseudomonas aeruginosa* and *Escherichia coli*).

## 3. Results and discussion

*3.1. Chemical structure confirmation*

The structures of the prepared Gemini cationic surfactant (G6, G8 and G10) were characterized using FTIR and $^1$H NMR: FTIR spectra ν = 3,416 cm$^{-1}$ $(CH_2)_{as}$, 2,856 cm$^{-1}$ $(CH_2)$, 2,612 cm$^{-1}$ ($-N^+$), 1,465 cm$^{-1}$ $(CH_2)_n$ and 1,662 cm$^{-1}$ (C=O) of aromatic aldehyde (Fig. 2). $^1$H NMR spectra δ = 1.26 ppm (m, 4H, C$\underline{H}_2$), 1.77 ppm (m, 4H, $CH_2C\underline{H}_2CH_2N^+$), 3.05 ppm (t, 4H, $CH_2C\underline{H}_2N^+$), 3.52 ppm (s, 12H, C$\underline{H}_3$N+), 6.80 ppm (d, 4H, $^+$NCC$\underline{H}$), 7.70 ppm (d, 4H, C$\underline{H}$CCHO), 9.67 ppm (s, 2H, CHCC$\underline{H}$O) Fig. 3.

*3.2. Surface properties of the prepared Gemini cationic surfactant*

*3.2.1. CMC and surface tension*

In the paragraphs and Fig. 4 and 5, both at 25°C and 40°C, the surface tension variation of the produced Gemini cationic surfactant (G6 as a typical molecule) in relation to log*C* is discussed. The surfactant particles concentration accumulated at the air/water interface, as indicated by the surface tension profile, and the curves eventually broke at the CMC. By sharply decreasing surface tension after increasing surfactant concentration in solution (CMC), the profile of surface tension was demonstrated [20]. The values of surface tension steadily decreased (G10) when the chain length of spacer increased from 1,6-dibromohexane (G6) to 1,10-dibromodecane (G10). The surfactant particles may be migrating toward the air/water interface as a result of an increase in the mutual discord between the polar water and the nonpolar hydrophobic chain. Chain lengths of spacer of the generated Gemini cationic surfactant particles steadily increased, but so did their CMC values; The CMC values significantly decreased as a result of the longer spacer chains' stronger attraction to the water phase (Table 1).

*3.2.2. Effectiveness ($\gamma_{CMC}$) and efficiency ($Pc_{20}$)*

The efficiency of the prepared Gemini cationic surfactants is determined by the difference in surface tension between the surfactant solution at the critical micelle concentration ($\gamma_{CMC}$) and the surface tension of distilled water ($\gamma_0$), as shown in Table 1 [21,22].

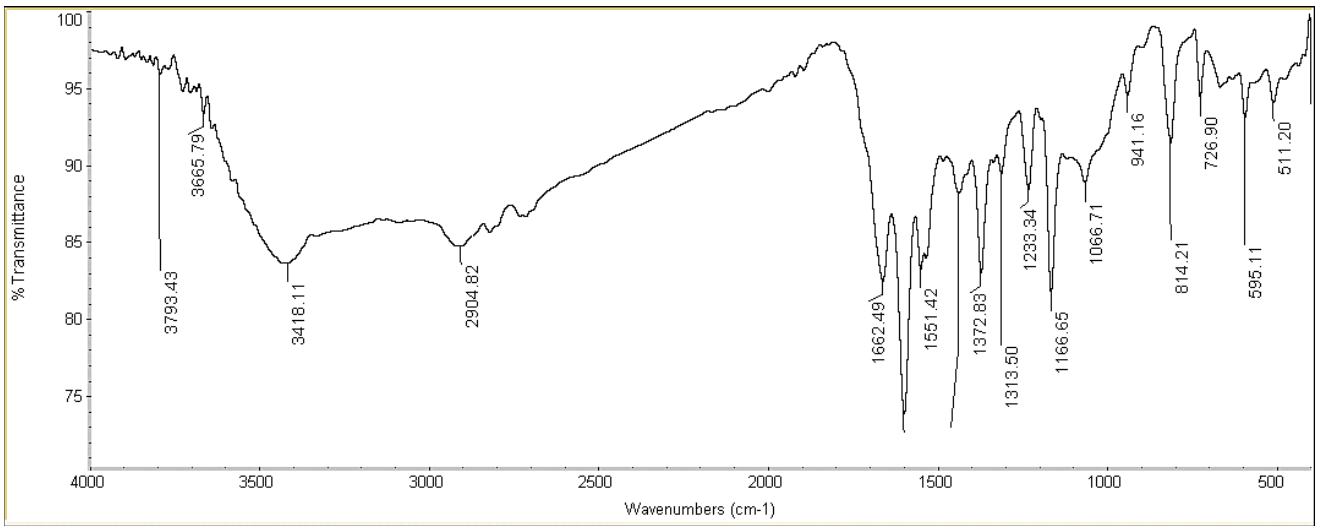
$$\pi_{CMC} = \gamma_0 - \gamma_{CMC} \quad (1)$$

In a sequence of surfactants, the molecules with lower surface activity have lower effectiveness values, and vice versa. According to the results presented in Table 1 (G6), the 1,6-dibromohexane derivative is clearly less surface active than the 1,8-dibromooctane, and 1,10-dibromodecane derivatives (G8 and G10).

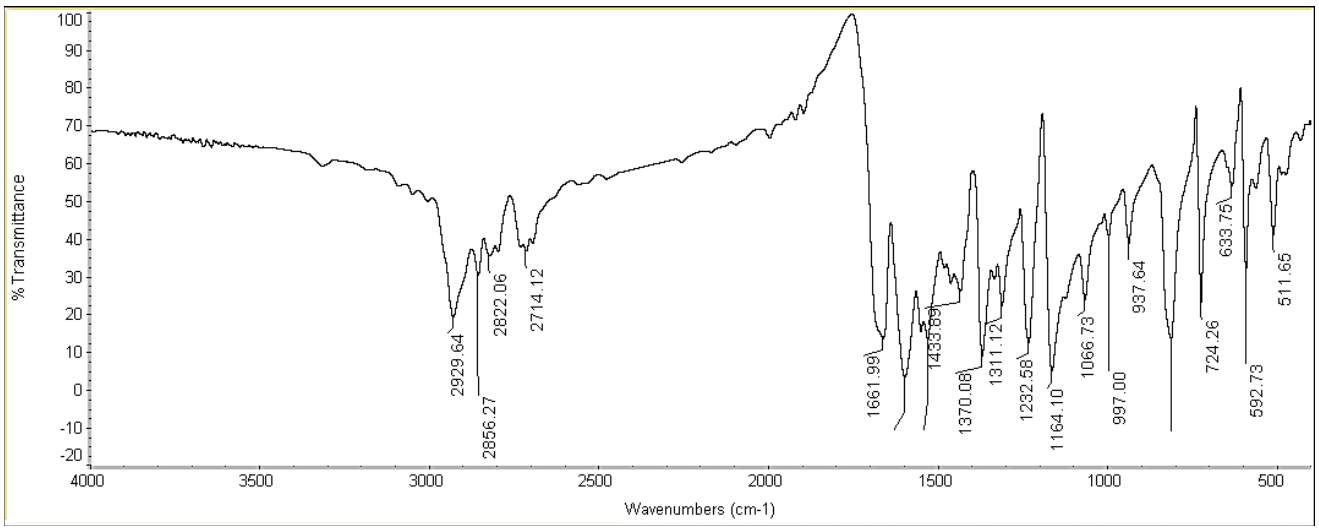
Efficiency, $Pc_{20}$ is the maximum surfactant concentration that can reduce the surface tension of a solution by 20 mN/m. Table 1 displays the Gemini cationic surfactant efficiency values. The effectiveness of the molecules decreases as the number of methylene groups ($-CH_2-$) in the spacer chains decreases, resulting in an increase in water hydrophobic interactions that lower surface tension (Table 1).

*3.2.3. Maximum surface excess ($\Gamma_{max}$) and minimum surface area ($A_{min}$)*

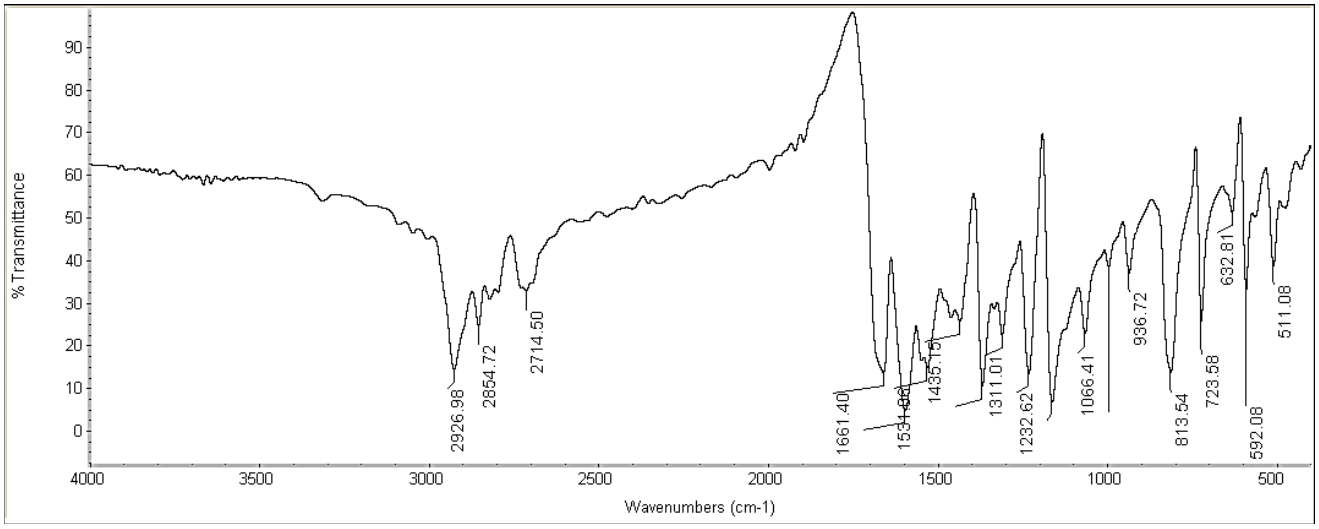
$\Gamma_{max}$, which describes the build-up of surfactant molecules at the air/water interface, The Gibb's equation can be used to calculate the maximum surface excess of the synthesised Gemini cationic surfactants [23].




G6




G8




G10

Fig. 2. Fourier-transform infrared spectrum of Gemini cationic surfactant (G6, G8 and G10).

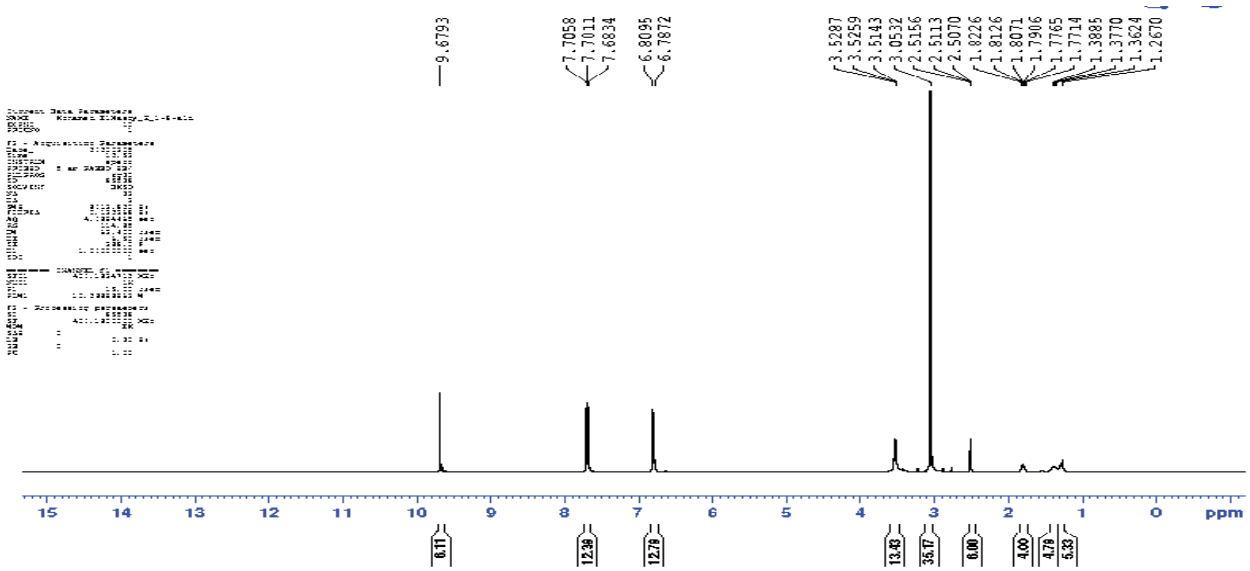



Fig. 3. Proton nuclear magnetic resonance ($^1$H NMR) spectrum of Gemini cationic surfactant (G6).

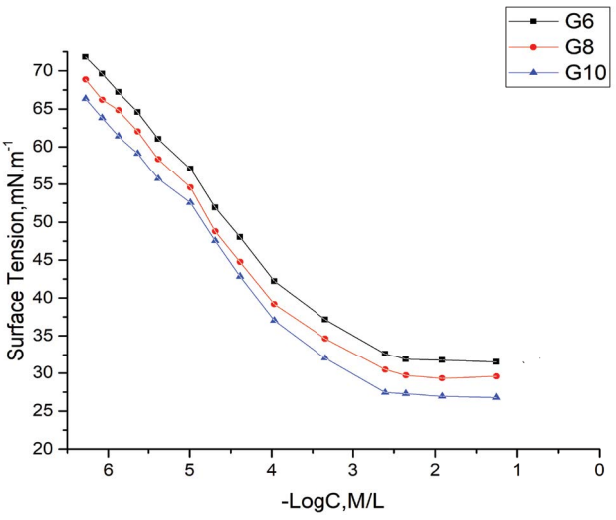



Fig. 4. Surface tension against −log concentration of surfactants (G6, G8 and G10) at 25°C.

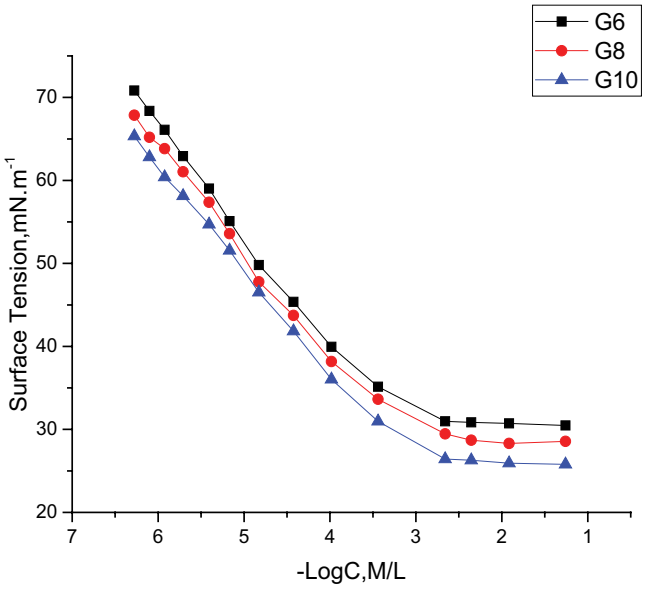



Fig. 5. Surface tension against −log concentration of surfactants (G6, G8 and G10) at 40°C.

$$\Gamma_{max} = \frac{1}{2.303nRT}\left(\frac{\partial\gamma}{\partial \mathrm{Log}C}\right) \quad (2)$$

where $n$ denotes the number of ionic species whose concentration at the interface varies with the concentration of surfactant in the solution. In Gemini surfactants, this number is equivalent to 3. $T$ is $t$ + 273 and $R$ is the gas constant (8.314 J/mol·K). Table 1 displays the maximum values of the synthesised Gemini cationic surfactants at various temperatures. The statistics in Table 1 show that the concentration of surfactant molecules near the interface gradually decreases as the spacer chain length increases. The average amount of surface area taken up by each surfactant molecule when adsorbed is shown in the Eq. (3) [13].

Table 1
Surface parameters of the surfactants at 25°C and 40°C

| Compound | Temp. | CMC (mM) | $\pi_{CMC}$ (mN/m) | $Pc_{20}$ (M/L) | $\Gamma_{max} \times 10^{-10}$ (mol/cm$^2$) | $A_{min}$ (Å) |
|---|---|---|---|---|---|---|
| G6 | 25 | 0.483 | 33 | 4.876 | 4.129 | 41.24 |
| G6 | 40 | 0.577 | 32 | 4.978 | 4.243 | 39.16 |
| G8 | 25 | 0.469 | 34 | 5.103 | 3.990 | 42.79 |
| G8 | 40 | 0.542 | 33 | 5.161 | 4.097 | 40.83 |
| G10 | 25 | 0.447 | 35 | 5.167 | 3.919 | 43.68 |
| G10 | 40 | 0.520 | 34 | 5.251 | 3.999 | 42.36 |

$$A_{\min} = \frac{10^{14}}{N_A \Gamma_{\max}} \tag{3}$$

where $N_A$ is Avogadro's number.

By increasing the length of the spacer chain, each surfactant molecule's average surface area at the interface is increased. At 25°C, the maximum surface area occupied at the interface was 41.22, while the minimum surface area was 43.48 when using G10 surfactant.

### 3.2.4. Emulsification power

The following measurements were made to determine the synthesized surfactants' emulsifying power. Time required to separate 9 mL of pure water from the formed emulsion containing paraffin oil and surfactant solution (0.1 wt.%) 10 mL). Fig. 6 shows the emulsifying power of synthetic Gemini cationic surfactants as a function of time at 25°C. More stable emulsions are formed when pure water is separated and emulsified, and vice versa. Performance is affected by the length of the spacer strand. It appears to be emulsified. Distance chain length is the only thing that can affect the strength of Gemini cationic surfactants that have been made.

A short spacer chain with an iso-methylene group (G6) is the lowest. Eight methylene groups significantly boost the emulsifying power of G8 300 s, which tends to emulsify at 150 s as spacer chain length increases. For 600 s, the longest spacer chain with 10 methylene groups (G10) is an oil/solution emulsion that is moderately stable. Due to their inability to form emulsions with oils, synthetic surfactants are not suitable for use in oil fields because they do not produce dimensionally stable emulsions, which can cause problems with water. The measurements of emulsification at the air-solution interface show that the results of these synthetic surfactants may be moderately affected by surface tension and desaturation concentration of various surfactants.

### 3.2.5. Foaming power

Foam is extremely dangerous when used in oil fields because it increases system pressure and increases the risk of a pipe explosion from high pressure fluid. Therefore, 100 mL of 0.1% surfactant was shaken to determine the effervescent strength of synthetic cationic Gemini surfactants. A 250 mL sealed graduated cylinder filled with a potent detergent solution kept at 25°C. Data are shown in Fig. 6, and it can be seen from the foam performance data that synthesised Gemini cationic surfactants exhibit a negligible tendency to foam. This is because the data are for educational purposes, and the compounds can be used as additives in oilfield applications or as detergents in washing machines (Fig. 7).

### 3.2.6. Standard free energy, entropy and enthalpy of micellization and adsorption

Gibbs equations were used to compute the produced Gemini cationic surfactant at 25°C, 45°C, and 55°C [24], This information is compiled in Table 2:

$$\Delta G^{\circ}_{\text{mic}} = nRT \log \text{CMC} \tag{4}$$

$$\Delta G^{\circ}_{\text{ads}} = \Delta G^{\circ}_{\text{mic}} - \left(0.06\pi_{\text{CMC}} A_{\min}\right) \tag{5}$$

$$-\Delta S^{\circ}_{\text{mic}} = \frac{\Delta G^{\circ}_{\text{mic}}}{\Delta T} \tag{6}$$

$$-\Delta S^{\circ}_{\text{ads}} = \frac{\Delta G^{\circ}_{\text{ads}}}{\Delta T} \tag{7}$$

$$\Delta H^{\circ}_{\text{mic}} = \Delta G^{\circ}_{\text{mic}} + T\Delta S^{\circ}_{\text{mic}} \tag{8}$$

$$\Delta H^{\circ}_{\text{ads}} = \Delta G^{\circ}_{\text{ads}} + T\Delta S^{\circ}_{\text{ads}} \tag{9}$$

Anywhere $n$ equals the amount of ionic species in the solution (3), $R$ equals the universal gas constant (8.314 J/mol·K), T equals the absolute temperature, $\pi_{\text{CMC}}$ equals the effectiveness, and $A_{\min}$ equals the minimum surface area.

The Gemini cationic surfactants that were created (G6, G8, and G10) demonstrated negative values for both micellization and adsorption, demonstrating that the processes were spontaneous. The free energy of micellization and adsorption decreases as the length of the spacer chain increases. The thermodynamic stability of the molecules at the air/water interface determines which process is preferred for adsorption, although high negativity $\Delta G_{\text{ads}}$

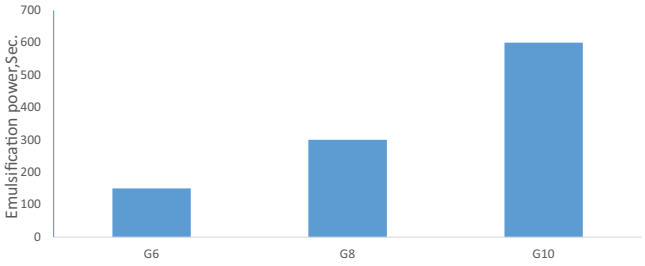



Fig. 6. Influence of hydrophobic spacer of Gemini cationic surfactant on emulsification power.

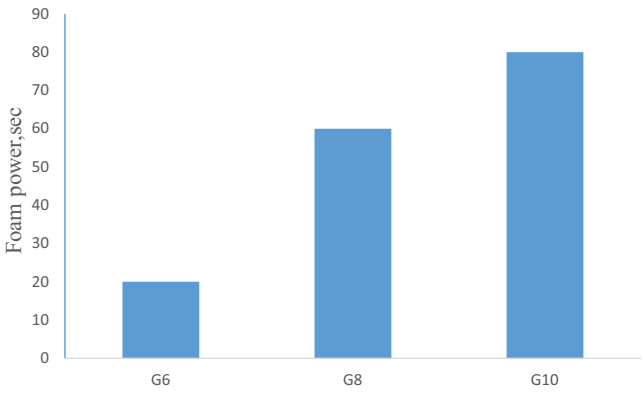



Fig. 7. Influence of hydrophobic spacer of Gemini cationic surfactant on foam high.

values showed that adsorption predominates over micellization. According to Table 2, the stability of the adsorbed and micellized surfactant molecules increases as the temperature rises from 25°C to 40°C when compared to the molecules that are freely diffused in the aqueous phase. The low value of the entropy change of micellization ($\Delta S_{mic}$) indicates that the molecules participating in the micellar phase of the resulting thick ammonium salt solution are ordered. The arrangement of the molecules reveals their compactness, the positive nitrogenous groups of the hydrophilic head entering directly into the aqueous phase, and the hydrophobic alkyl chains having good compatibility in the micellar core. This configuration reduces the repulsive forces in the surfactant aqueous system and stabilizes the resulting micelles. The order of enthalpy changes ($\Delta H°_{ads/mic}$) in Table 2 indicates that the adsorption process rather than the micellization process has a thermodynamic advantage for the resulting surfactant.

### 3.3. Antimicrobial action of prepared Gemini cationic surfactants

Several cationic surfactants are used as insecticides and antimicrobials because quaternary nitrogen compounds behave as amphiphilic cations in aqueous solution [5,24,25]. Therefore, the efficacy of cationic surfactants to prevent the growth of harmful fungi, Gram-positive (*S. aureus* and *B. subtilis*), and Gram-negative (*E. coli* and *P. aeruginosa*) bacteria was examined (*C. albicans* and *A. niger*). It is clear from the data in Table 3 and Fig. 6 that the hydrophobic chain length has a higher impact on the antibacterial properties of prepared surfactants that was created. As a result, as the chain length of spacer was extended, the antibacterial activity gradually rose. The Gram-positive and Gram-negative microorganisms under examination showed the greatest antibacterial activity against the N1, N6-bis (4-formylphenyl)-N1, N6-tetramethyldecane-1, 6-diaminium bromide (G10). These could occur from the interaction between the surface activities and antibacterial qualities of the synthetic compounds. Long chain increases the propensity of the generated biocide molecules to adsorb at membrane surfaces. The potent activity of the tested medications is enhanced because of their dense population at the cellular membrane [26,27]. Gram-positive bacteria are more resistant to the synthesised Gemini surfactants' antibacterial effects than Gram-negative bacteria as a whole. The different cell membrane topologies of the two species of bacteria can account for this (Fig. 8). Because the outer layer of Gram-negative bacteria's outer membrane is almost entirely constituted of proteins and lipopolysaccharides, which block the entry of biocides and amphiphilic chemicals, Gram-negative bacteria are more resistant than Gram-positive bacteria [28]. Alkyl chain length often affects antimicrobial efficacy. Alkyl chain length has been found to be linearly related to antimicrobial activity. The length of the hydrocarbon spacer between the two ammonium groups is another structural factor. According to Table 3, Gemini surfactants in 10 carbon buffers have higher activity than

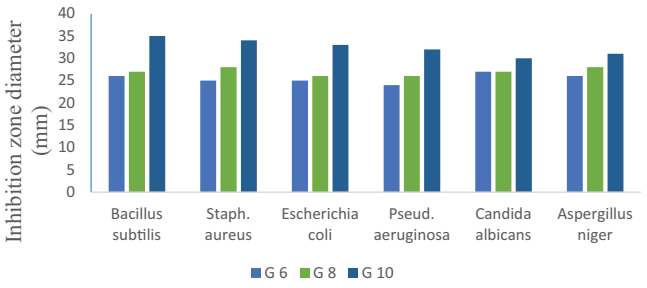



Fig. 8. Antimicrobial action of Gemini cationic surfactants (G6, G8 and G10) against dissimilar microorganism.

Table 2
Thermodynamic parameters of the surfactants at 25°C and 40°C

| Compound | $T$ (°K) | $\Delta G°_{ads}$ (kJ/mol) | $\Delta G°_{mic}$ (kJ/mol) | $\Delta S°_{ads}$ (kJ/mol) | $\Delta S°_{mic}$ (kJ/mol) | $\Delta H°_{ads}$ | $\Delta H°_{mic}$ |
|---|---|---|---|---|---|---|---|
| G6 | 298 | –25.61 | –24.74 | – | – | – | – |
| G6 | 313 | –26.27 | –25.36 | 1.738 | 1.69 | 517.72 | 503.44 |
| G8 | 298 | –25.68 | –24.83 | – | – | – | – |
| G8 | 313 | –25.98 | –25.27 | –1.66 | 1.62 | –545.56 | –546.17 |
| G10 | 298 | –25.96 | –25.22 | – | – | – | – |
| G10 | 313 | –26.55 | –25.66 | –1.65 | 1.60 | –542.31 | –527.66 |

Table 3
Antimicrobial activity of the tested substances measured by (mm)

| Test organism compound | *Bacillus subtilis* | *Staphylococcus aureus* | *Escherichia coli* | *Pseudomonas aeruginosa* | *Candida albicans* | *Aspergillus niger* |
|---|---|---|---|---|---|---|
| G6 | 24 | 23 | 23 | 22 | 25 | 24 |
| G8 | 25 | 26 | 24 | 24 | 25 | 26 |
| G10 | 36 | 32 | 31 | 30 | 28 | 29 |
| References | 29 | 30 | 27 | 28 | 26 | 29 |

their 6 and 8 carbon buffer equivalents. Furthermore, the results of biological studies on the antifungal activity of the test biocides against pathogenic fungal strains (*C. albicans* and *A. niger*) showed promising features of the biocide's mechanism of action. It can be explained as follows. Gram-positive bacteria adsorb to the lipoteichoic acid layer. This layer is characterized by its charged nature and ability to interact with the positive charge of the intramolecular quaternary nitrogen. In Gram-negative bacteria, on the other hand, the lipid layer characterized by high hydrophobicity becomes a point of attack for positively charged biocides. Selective permeabilization of basement membranes can be disrupted by adsorption of biocides, thereby significantly inhibiting biological reactions within cells. The presence of a counterion as a chloride atom ($Br^-$) enhances its potent effect in penetrating the basement membrane [2,29].

## 4. Conclusion

Because Gemini surfactants are tunable and designer chemicals, they are used in a wide variety of applications. For this reason, a new type of 4-(dimethylamino)benzaldehyde based on Gemini surfactants was developed. The interesting point of these surfactants is their low CMC and high effectiveness in reducing the surface tension of water due to their chemical structure. The length of the spacer strand is affected. In the series of homogeneous ionic liquids studied, the propensity to form micelles increases and the CMC decreases regularly with the length of the alkyl spacer of the polar head group. Hydrophobic interactions between their alkyl chains are therefore likely to be the main driving force behind the micelle formation of these Gemini cationic surfactants. The studied Gemini surfactant showed antibacterial activity. Their effectiveness as antimicrobial marketers depends on the duration of the spacer alkyl chain. Compounds with short spacers are much less active against microorganisms and fungi, and surfactants with 10 carbon atoms in the spacer chain have shown broad antimicrobial interest. Evaluation of antimicrobial interest vs. soil interest of Gemini surfactants confirms that log CMC can be used as a surprising hydrophobicity index to estimate performance as an antimicrobial marketer. Compared to standard cationic surfactants such as alkyl trimethyl ammonium compounds, these amphiphilic compounds have little effect on soil. The antibacterial activity of Gemini surfactants against Gram-Nice microbes was comparable or possibly superior to that observed using the cationic surfactant cetyltrimethylammonium chloride. Classic antibacterial agent. Advanced information on the structural parameters that affect soil budgets and the long-chain (10 carbon atoms) organic interest defined in these paintings will lead to novel pharmaceuticals, advanced physico-chemical and organic studies for engineering. It is presented as a useful resource for the layout and selection of surfactants with budgets. Applications in the oil field.

The synthesized compounds were evaluated for antibacterial activity using the agar diffusion technique (Shaban et al., 2016).

Test compounds were tested against Gram-positive bacteria (*Bacillus subtilis* ATCC 6633, *Staphylococcus aureus* ATCC 35556), Gram-negative bacteria (*E. coli* ATCC 23282 and *Pseudomonas aeruginosa* ATCC 10145), yeast (*Candida albicans* IMRU 3669), and filamentous fungi (*Aspergillus*) tested against (*Niger* ATCC 16404). Bacteria and yeast were cultured on nutrient agar and fungi were cultured on Czapek's Dox agar. Test compounds were evaluated at a concentration of 5,000 ppm.

Positive controls were bacterial erythromycin, yeast nalidixic acid, and metronidazole fungi. All studies were performed in duplicate and the data presented are the average of the results obtained.

## References

[1] F.M. Menger, V.A. Seredyuk, R.P. Apkarian, E.R. Wright, Colloidal assemblies of branched Geminis studied by cryo-etch-HRSEM, J. Am. Chem. Soc., 124 (2002) 12408–12409.
[2] M. Bekhit, N.A. Negm, N.R. Abd El-Rahman, M. Fekry, Synthesis and evaluation of Gemini cationic surfactant based on 4-(4-nitrobenzyl)pyridine: surface and biological activities, Desal. Water Treat., 274 (2022) 150–158.
[3] S.M. Tawfik, Synthesis, surface, biological activity and mixed micellar phase properties of some biodegradable Gemini cationic surfactants containing oxycarbonyl groups in the lipophilic part, J. Ind. Eng. Chem., 28 (2015) 171–183.
[4] I. Aiad, M.I. Marzouk, S.A. Shaker, N.E. Ebrahim, A.A. Abd-Elaal, S.M. Tawfik, Antipyrine cationic surfactants capping silver nanoparticles as potent antimicrobial agents against pathogenic bacteria and fungi, J. Mol. Liq., 243 (2017) 572–583.
[5] N.A. Negm, S.M. Tawfik, M.I. Abdou, E.A. Badr, F.M. Ghuiba, Evaluation of some nonionic surfactants derived from tannic acid as additives for water-based mud, J. Surfactants Deterg., 18 (2015) 309–319.
[6] E. Setiawan, K. Wijaya, M. Mudasir, QSAR modeling for predicting the antifungal activities of Gemini imidazolium surfactants against *Candida albicans* using GA-MLR methods, J. Appl. Pharm. Sci., 11 (2021) 22–27.
[7] B.E. Brycki, A. Szulc, I. Kowalczyk, A. Koziróg, E. Sobolewska, Antimicrobial activity of Gemini surfactants with ether group in the spacer part, Molecules, 26 (2021) 5759, doi: 10.3390/molecules26195759.
[8] M.R. Garipov, A.E. Sabirova, R.S. Pavelyev, N.V. Shtyrlin, S.A. Lisovskaya, O.V. Bondar, A.V. Laikov, J.G. Romanova, M.I. Bogachev, A.R. Kayumov, Y.G. Shtyrlin, Targeting pathogenic fungi, bacteria and fungal-bacterial biofilms by newly synthesized quaternary ammonium derivative of pyridoxine and terbinafine with dual action profile, Bioorg. Chem., 104 (2020) 104306, doi: 10.1016/j.bioorg.2020.104306.
[9] Z. Hafidi, L. Yakkou, F.-E. Guouguaou, S. Amghar, M. El Achouri, Aminoalcohol-based surfactants (N-(hydroxyalkyl)-N, N-dimethyl N-alkylammonium bromide): evaluation of antibacterial activity and molecular docking studies against dehydrosqualene synthase enzyme (CrtM), J. Dispersion Sci. Technol., 42 (2021) 514–525.
[10] A. Pinazo, R. Pons, L. Pérez, M.R. Infante, Amino acids as raw material for biocompatible surfactants, Ind. Eng. Chem. Res., 50 (2011) 4805–4817.
[11] S.M. Shaban, A.S. Fouda, S.M. Rashwan, H.E. Ibrahim, M.F. Elbhrawy, Inhibitive action of new synthesized cationic surfactant with free hydroxyl group on the C1018 steel corrosion: experimental and theoretical investigations, Prot. Met. Phys. Chem., 54 (2018) 709–723.
[12] I. Aiad, M. Abo Riya, S.M. Tawfik, M.A. Abousehly, Synthesis, surface properties and biological activity of N,N,N-tris(hydroxymethyl)-2-oxo-2-(2-(2-(alkanoyloxy) ethoxy) ethoxy) ethanaminium chloride surfactants, Egypt. J. Pet., 25 (2016) 299–307.
[13] S.M. Tawfik, N.A. Negm, M. Bekheit, N.R. Abd El-Rahman, A.A. Abd-Elaal, Synergistic interaction in cationic antipyrine/CTAB mixed systems at different phases, J. Dispersion Sci. Technol., 43 (2022) 1663–1673.

[14] S.M. Tawfik, N.A. Negm, Synthesis, characterization and evaluation of some anionic surfactants with phosphate group as a biodegradable corrosion inhibitor for carbon steel in acidic solution, J. Mol. Liq., 215 (2016) 185–196.
[15] D. Xu, X. Ni, C. Zhang, J. Mao, C. Song, Synthesis and properties of biodegradable cationic Gemini surfactants with diester and flexible spacers, J. Mol. Liq., 240 (2017) 542–548.
[16] A. Laschewsky, K. Lunkenheimer, R.H. Rakotoaly, L. Wattebled, Spacer effects in dimeric cationic surfactants, Colloid. Polym. Sci., 283 (2005) 469–479.
[17] A. Labena, A. Hamed, E.H.I. Ismael, S.M. Shaban, Novel Gemini cationic surfactants: thermodynamic, antimicrobial susceptibility, and corrosion inhibition behavior against *Acidithiobacillus ferrooxidans*, J. Surfactants Deterg., 23 (2020) 991–1004.
[18] M.T. Garcia, O. Kaczerewska, I. Ribosa, B. Brycki, P. Materna, M. Drgas, Biodegradability and aquatic toxicity of quaternary ammonium-based Gemini surfactants: effect of the spacer on their ecological properties, Chemosphere, 154 (2016) 155–160.
[19] N. Ferlin, M. Courty, S. Gatard, M. Spulak, B. Quilty, I. Beadham, M. Ghavre, A. Haiß, K. Kümmerer, N. Gathergood, Biomass derived ionic liquids: synthesis from natural organic acids, characterization, toxicity, biodegradation and use as solvents for catalytic hydrogenation processes, Tetrahedron, 69 (2013) 6150–6161.
[20] N.R. Abd El-Rahman, M. Bekhit, M. Fekry, Fabrication and evaluation of polyurethane cationic surfactants, and their potential on silver nanoparticles stability, surface activity, and biological activity, Egypt. J. Pet., 31 (2022) 23–31.
[21] M.F. Zaky, I.A. Aiad, S.M. Tawfik, Synthesis, characterization, surface and biocidal effect of some germinate nonionic surfactants, J. Ind. Eng. Chem., 21 (2015) 1174–1182.
[22] W.L. Hinze, E. Pramauro, A critical review of surfactant-mediated phase separations (cloud-point extractions): theory and applications, Crit. Rev. Anal. Chem., 24 (1993) 133–177.
[23] X. Cao, Z. Li, X. Song, X. Cui, Y. Wei, F. Cheng, J. Wang, Effects of spacers on surface activities and aggregation properties of anionic Gemini surfactants, J. Surfactants Deterg., 12 (2009) 165–172.
[24] I. Aiad, M.M. El-Sukkary, A. El-Deeb, M.Y. El-Awady, S.M. Shaban, Surface properties, thermodynamic aspects and antimicrobial activity of some novel iminium surfactants, J. Surfactants Deterg., 15 (2012) 359–366.
[25] S. Augusta, H. Gruber, F. Streichsbier, Synthesis and antibacterial activity of immobilized quaternary ammonium salts, J. Appl. Polym. Sci., 53 (1994) 1149–1163.
[26] N.A. Negm, S.M.I. Morsy, M.M. Said, Biocidal activity of some Mannich base cationic derivatives, Bioorg. Med. Chem., 13 (2005) 5921–5926.
[27] M. Khowdairy, M. Mohamed, A. Mohamed, Surface and biological activity of some prepared quaternary ammonium surfactants, J. Dispersion Sci. Technol., 32 (2011) 760–769.
[28] D.M. Hamed, Antibiotics profile and β-lactamases in *Pseudomonas aeruginosa*, Rec. Pharm. Biomed. Sci., 5 (2021) 74–79.
[29] L. Chernomordik, M.M. Kozlov, J. Zimmerberg, Lipids in biological membrane fusion, J. Membr. Biol., 146 (1995) 1–14.